APPLICATION FOR UNITED STATES PATENT
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FOR

SYSTEM AND METHOD FOR CONTINUOUS INTEGRITY TESTING OF A MATERIAL WEB

DOCKET NO. 72162-250779

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EXPRESS MAIL NO. EL 724 025 981 US

SYSTEM AND METHOD FOR CONTINUOUS INTEGRITY TESTING OF A MATERIAL WEB

FIELD OF INVENTION

The present invention is related to manufacturing porous media and dense films, and particularly to a system and method for detecting a defect therein.

BACKGROUND

It is often desirable to test porous media, e.g., filtration membrane media, or dense film for defects, such as enlarged or misshapen pores or holes. One non-destructive test commonly used to test for defects is known as the "bubble-point test." As described in U.S. Patent No. 5,064,529 to Hirayama et al. and U.S. Patent No. 5,576,480 to Hopkins et al., the bubble point of a porous medium may be discovered by first impregnating the porous medium or dense film with a liquid (such as distilled water) and then forcing a gas through the porous medium at a known pressure. In the case of a filtration medium, this may be accomplished by mounting the filtration medium on a supporting body with inlet and outlet ends and immersing the filtration medium in a bath of the impregnating liquid while segregating the internal chamber of the supporting body from the liquid. The internal chamber of the supporting body may be supplied with fixed pressure or variable pressure gas from a gas source.

The pressure at which the gas forces the liquid out of a pore or defect in the porous medium or dense film is dependent upon the size of the pore or defect, the surface tension characteristics of the liquid in the pores or defects of the porous medium or dense film, and the wetting angle of the interface between the filter medium material and the pore/defect liquid. Their relationship may be ideally approximated for circular pores and defects according to Laplace's Law, i.e.,

$$P = 2(\gamma \cos \theta)/r \qquad \text{(I)}$$

where P = the bubble point pressure, i.e., the point at which the gas expels liquid from the pore;

γ = a surface tension coefficient for the liquid in the pore or defect, which may depend upon the liquid and the porous medium or dense film material;

θ = the contact angle of the interface; and

r = the radius of the pore or defect.

As described by Laplace's Law (I), as the radius (size) of a pore increases, the bubble point pressure for the pore or defect will decrease. The bubble point can be visibly detected by the formation of gas bubbles on the submerged surface of the porous medium. The pressure at which gas is supplied at the internal chamber of the supporting body may be increased from an initially low value to precisely locate defects of various sizes. In such a testing procedure, the first bubbles will be visible at the largest defects.

Present systems for submersion testing of porous media and dense films, and particularly, filtration membranes, using the bubble point test have been ill-suited for continuous testing prior to forming large webs of the porous media or dense film into smaller elements that are formed around a supporting body. It is generally necessary to test smaller elements instead of continuous webs of porous media or dense films because liquid baths in which the porous media or dense film elements are submerged are of limited size and an internal chamber of limited size is needed to apply gas to an internal surface of the porous media element. Accordingly, when defects have been detected in a formed element, there has been little that can be cost-effectively done to repair the defect. Thus defective elements generally go to waste, increasing the overall cost of production of porous media and dense film products.

Alternatively, porous membrane and dense film elements are mounted, wetted and subjected to air pressure on one side (in the case of a cylindrical element, either the inner or outer surface of the element). Bubble point pressure is determined by measuring air flow downstream of the wetted filter element. As the air pressure applied is varied to exceed the defect bubble point pressure, the down stream air flow changes sharply, indicating that an unsuitably large defect is present somewhere within the element. These types of tests do not allow for the precise

location of defects. Rather, they provide only information as to the suitability of an entire element for a particular application.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts an portion of a defect detection system according to an embodiment of the present invention;

FIG. 2 depicts a vacuum roller that may be used in an embodiment of the invention;

FIG. 3 shows a captured image according to an embodiment of the invention; and

FIG. 4 depicts an alternative embodiment of the present invention including a post-processing device.

DETAILED DESCRIPTION

Embodiments of the present invention relate to a system and method for detecting defects in porous media or dense films using a vacuum roller(s) and an automated vision system to perform a bubble point or similar integrity test. Embodiments of the system are capable of detecting defects in continuous webs of porous media or dense films, thereby allowing for the detection, marking and/or repair of defects prior to formation of the porous media or dense films into individual elements. The approach of the present invention may also reduce the sizes of liquid baths and amounts of liquid needed to perform defect tests.

Although the following description focuses on embodiments of the present invention for locating defects in porous material webs, it will be readily understood that the invention may be used for detecting defects in other types of materials including dense films and can be used for detecting any defects that can be characterized by a bubble point pressure. Accordingly, although such a film will not have "pores," a dense film should be treated as a type of "material web" for all other purposes in the following discussion. Furthermore, the term "material web" is also intended to include woven and non-woven mats.

FIG. 1 illustrates a defect detection system according to an embodiment of the present invention. The material web **1** may be a continuous web of porous medium material (as shown in FIG. 1) or a dense film. The material web **1** may have a specified desired bubble point pressure, e.g., 100 mm Hg. In the case of a dense film, the desired bubble point pressure may be equivalent to the pressure at which the material would be torn or ruptured.

In the porous material web 1 shown in FIG. 1, a properly formed pore **1a** (shown in magnified view **A**, **B**, and **C** of a portion of the face of the material web **1**) may, therefore, have a bubble point pressure substantially equal to the desired bubble point pressure of the material web **1**. A defect **1b** (shown in magnified views **A**, **B**, and **C**) in the material web may have a bubble point pressure that is substantially lower than the desired bubble point pressure, which may indicate that the defect **1b** is significantly larger than a properly formed pore **1a** and, possibly, unsuitable for an application in which the porous medium is to be used. For example, in a

filtration application, the porous medium may be needed to filter out particles of a size smaller than the defect **1b**.

The material web **1** may be wetted with a liquid **5** in a liquid bath **4** so that the liquid fills substantially all of the pores **1a** and defects **1b** of the material web **1** (as shown by the hatching in magnified view **B**). To wet the material web **1**, the material web **1** may begin with the pores **1a** and defects **1b** empty of the liquid **5**. The material web **1** may be fed around a first roller **2a**, which may be wholly or partially (as shown in FIG. 1) submerged below the surface of the liquid **5** in the liquid bath **4**. Alternatively, in a dense material web **1**, only defects **1b** may be filled with liquid **5** during the wetting process.

In alternative embodiments of the system, multiple rollers may be wholly or partially submerged below the surface of the liquid **5** in the liquid bath **4** and the material web **1** may be fed around the multiple rollers to lengthen the amount of time that the material web **1** is submerged in the liquid **5** to allow the liquid **5** to enter the pores **1a** and defects **1b**. In embodiments of the invention, the first roller **2a** may also be a vacuum roller and vacuum force may be applied to the material web **1** by the first roller **2a** to draw the liquid **5** into the pores **1a** and defects **1b**.

The wetted material web **1** may then be fed to a vacuum roller **3**. The arrows in FIG. 1 indicate the direction of feed of the material web **1** and the direction of rotation of the vacuum roller **3**, the first roller **2a** and a second roller **2b**. The wetted material web **1** may be held in contact with the vacuum roller **3** by vacuum pressure, gravity, tension in the material web created by the positioning of the first roller **2a** and second roller **2b** and/or some other force. Where the material web **1** contains very small pores, fluid retained in the membrane pores due to capillary forces may minimize or prevent air flow through the material web **1**. This allows vacuum pressure to build up so as to hold the material web **1** in contact with the vacuum roller **3** as the vacuum roller **3** turns. Similarly, vacuum pressure may hold a dense film material web **1** against the surface of the vacuum roller **3**. A shield **7** may be mounted inside (as shown) or outside the vacuum roller.

When vacuum pressure from the vacuum roller **3** is applied to the material web **1**, the liquid **5** may be drawn out of the pores **1a** (for a porous medium, as shown in FIG. 1) and defects **1b** of the material web **1** (as shown in magnified view **C**) by the differential pressure created by the vacuum. Whether the liquid **5** is drawn out of a particular pore **1a** or defect **1b** may depend upon the size and shape of the pore **1a** or defect **1b**, the contact angle between the solid material encircling a pore **1a** or defect **1b** in the material web **1** and the liquid in the pore **1a** or defect **1b**, and the amount of differential pressure created across the material web **1** by the vacuum roller **3**. The liquid **5** removed from the material web **1** may be drawn into the vacuum roller **3** and subsequently drained away.

The amount of differential pressure applied across the material web **1** may be set according to the sizes and shapes of defects whose detection is desired, the requirements for a particular application of the material web **1**, or other factors. In embodiments of the invention, the material web **1** may be subjected to vacuum pressure from a number of vacuum rollers and each vacuum roller may apply a different amount of pressure so that each vacuum roller may be used to detect a different set of defect shapes and sizes. Alternatively, a single vacuum roller **3** may apply increasing amounts of vacuum pressure throughout the time period for which the material web **1** is in contact with the vacuum roller **3**. By applying different vacuum pressures to the material web **1**, defects **1b** of different sizes can be detected, since each successive application of a vacuum pressure may be used to identify sets of defects **1b** within a particular size/shape range.

In embodiments involving successive applications of vacuum pressure, it may be desirable to rewet the material web **1** between applications of vacuum pressure. Alternatively, successively higher vacuum pressures may be applied to the material web **1** so that defects **1b** of different sizes can be detected without the material web **1** having to be rewetted. For example, in an embodiment of the invention, vacuum pressure may be applied to create a differential pressure of 20 mm Hg across the material web **1**. Under this differential pressure, liquid **5** may be removed from defects **1b** that are relatively large in size. The material web may then be

placed in contact with a second vacuum roller capable of applying vacuum pressure to the material web **1** sufficient to create a differential pressure of 40 mm Hg across the material web **1**. In this step, liquid **5** may be removed from smaller defects **1b**.

In embodiments of the system and method intended for use in detecting defects in a dense film, only defects may be filled with liquid prior to the application of differential pressure. In such methods and systems, a differential pressure higher than the bubble point pressure of the defects may be applied to the dense film to draw the liquid from the defects.

In embodiments of the invention, defects **1b** may be identified using a camera **6**. The term "camera" means any image capturing device including, without limitation, a video camera, still camera, digital camera, charge-coupled device (CCD) camera, infrared camera or sensing array, etc. The camera **6** may capture an image of a portion of the material web **1** surface. The process of capturing an image may include preparing the image for storage on a computer readable medium by, for example, cropping a snapshot-type image to center around a particular target, editing a video clip to include only a portion of the frames taken by the camera, dividing the image into multiple pixels, and/or digitally editing the image to improve picture quality. For an image composed of multiple frames, the frame rate of image capture may differ from the frame rate at which the image or a portion thereof is replayed. For example, the frame rate of replay may be slower that the frame rate of capture.

The image (or a portion thereof) may be stored on an appropriate medium. For example, in an embodiment of the invention, an electronic image of the material web **1** surface may be captured using a digital camera and may be stored on a SmartMedia card, ClikStick, floppy disk, compact disk (CD), digital video disk (DVD), hard drive or other computer readable medium. The storage medium may be locally attached to the camera **6** or may be remotely connected to a communication network, such as, the Internet, a local area network (LAN), wide area network (WAN) or metropolitan area network (MAN), to which the camera **6** is also attached. In an embodiment of the present invention, the image may be transmitted in real-time from the camera **6** to a central server and stored therein.

In an embodiment in which the camera **6** captures an electronic image of the material web **1**, the image may be transmitted to a central server using either wireless or wire-based communication channels. Examples of wire-based transmission include coaxial cable, twisted-pair telephone wire, electric power line, fiber optics, leased lines, and the like. Examples of wireless transmission include cellular, satellite, radio frequency, microwave, and like communication systems. In an embodiment in which the camera **6** captures a physical image of the signing event, the physical image may be converted to an electronic image using a document imaging device such as a scanner (not shown) and then transmitted to server. The central server may then store the electronic image in memory.

In embodiments of the invention, the camera **6** may be an infrared camera, such as the ThermaCam® line of thermal imaging cameras manufactured by FLIR Systems, Inc. of Portland, Oregon, which captures thermal images of portions of the surface of the material web **1** when the portions are in contact with the vacuum roller **3** or thereafter. FIG. 3 illustrates an example of a thermal image that may be captured by the camera **6** according to an embodiment of the invention. Although the thermal image in FIG. 3 is shown in black-and-white (using varying shades of gray), it should be understood that thermal images according to embodiments of the present invention may be in color.

In such embodiments, when vacuum pressure applied to the material web **1** draws liquid **5** from a defect **1b**, air may also be drawn through the defect **1b** by the vacuum pressure. If the temperature of the air drawn through the defect **1b** differs from the temperature of the material web **1**, the passing of the air through the defect **1b** will cause convective cooling or heating (depending on whether the air is warmer or cooler than the material web **1**) of the material web **1** material surrounding the defect **1b**. This change in temperature may appear on a thermal image of the material web **1** surface as a discoloration. The convective cooling or heating effect may be accentuated by increasing the difference in temperature between the liquid **5** in the liquid bath **4** and the air drawn into the defects **1b** by the vacuum pressure applied by the vacuum roller **3**.

As shown in FIG. 3, the image may be pixelated and the pixelated image may be processed to identify the defects **1b** through which air is being drawn by the vacuum roller **3**, i.e., defects whose bubble point pressure has been exceeded. The processing may include making areas of discoloration **202** more prominent by locally increasing image contrast, associating the color(s) of a pixel(s) with a numerical value(s) for purposes of comparing one pixel **201** to another, aggregation of neighboring pixels **201**, identification of sharp changes in pixel color (e.g., to identify color change boundaries), resizing of the image to compensate for capture angle, reweighting of pixel colors to account for known factors affecting thermal imagery (e.g., calibration of the camera **6** optics, known thermal patterns associated with convection from movement of the material web **1** or conduction by the vacuum roller **3**, etc.) and the like. The pixel resolution of the image may be chosen based on the size of the pores **1a** in the material web **1**. For example, the pixel size may be chosen to be roughly equal to the size of an image of a single pore **1a**.

Images of the material web **1** surface captured by the camera may be associated with information that may be used to determine the location of image features on the material web **1** surface. For example, in an embodiment of the invention, images may be time-stamped with information indicating when the image was captured. Information related to the speed and direction of travel of the material web **1** (e.g., the rotation speed of a driven roller) may also be stored. Based on the image's time of capture and the speed and direction of travel of the material web **1**, the current location of a surface feature appearing in the captured image may be precisely calculated.

In alternative embodiments, the camera **6** may be a digital camera and the image captured may be either a color or black-and-white photographic image. The image may be pixelated and processed to compare one or more pixels **201** to known images associated with the drawing of air through defects **1b** or known images of non-defective portions of the material web **1**.

Note that while the prior discussion has focused on the use of a vacuum roller **3** to draw air into the defects **1b** in the material web **1**, in other embodiments of the invention, the vacuum

roller **3** may be replaced with a roller which attempts to force air out through the defects **1b** in the material web by supplying air at a given pressure to the surface of the material web **1** in contact with the roller. In such embodiments, the camera **6** may capture thermal images, and the temperature of the air forced out of the roller may be controlled to increase the contrast of the thermal image at points associated with the defects **1b**. Alternatively in such embodiments, the camera **6** may capture photographic images, and portions of the image may be compared against known images of bubbles, examined for contours or shapes associated with bubbles and/or compared against known images of non-defective portions of the material web **1**.

A commercially available or customized software package may be used to perform image data processing, produce output control signals, and the like. One such software package is LabView offered by National Instruments of Austin, Texas. The software package may receive input data related to an image of the material web **1** or a portion thereof and may process this data to determine whether a defect **1b** can be identified. If such a defect can be identified, the software package may produce output data corresponding to the location of the identified defect, a control signal for repair equipment, and/or the like.

Movement of the material web **1** may be accomplished by driving the first roller **2a**, the second roller **2b**, the vacuum roller **3** or some combination thereof. The speed of movement of the material web **1** may depend upon the size and rotation speed of the driven roller(s). If multiple driven rollers are used, their rotation speeds may be matched so as not to apply excessive tension to the material web **1**. In embodiments of the invention, the axles on which the first roller **2a**, second roller **2b** or vacuum roller **3** are mounted may be moved (e.g., within a slot) to apply a desired amount of tension to the material web **1**.

A greater range of defects **1b** may be identified in embodiments in which a greater range of differential pressures can be applied to the material web **1**. The range of differential pressure that can be applied by an ideal vacuum roller is limited to the atmospheric pressure in which the vacuum roller is being operated. Therefore, to increase the range of applied differential

pressures, in embodiments of the invention, the integrity testing described above may be performed within a pressure chamber with an increased atmospheric pressure.

As shown in further detail in FIGURE 2, in some embodiments, the vacuum roller **3** may include a cylindrical member **103** constructed of a porous material such as polypropylene or perforated stainless steel. The cylindrical member may rotate about an axle **105**, which may be supported by one or more axle bearings **108** and fixed supports **109a**. The outer surface of the cylindrical member **103** may be machined to a smoothness necessary to prevent the introduction of surface defects to the material web via contact with the outer surface of the cylindrical member **103**. The cylindrical member **103** may have multiple openings **101** extending from its interior vacuum chamber **102** to the outer surface of the cylindrical member **103**. The size of the openings **101** may affect the amount of vacuum pressure that can be produced by the vacuum roller. The openings **101** may be located uniformly throughout the cylindrical member **103** and some of these openings **101** may be blocked by a shield **107** so that only the openings **101** that are not blocked by the shield **107** transmit vacuum pressure from the interior vacuum chamber **102** to the outer surface of the cylindrical element **103**. Alternatively, only a portion of the cylindrical element **103** may have the openings **101**. The openings **101** need not be circular. In some embodiments, the openings in the cylindrical member **103** may take the shape of lateral channels. The size and pattern of the openings **101** may be selected to ensure that substantially all portions of the material web **1** are subjected to vacuum pressure. Alternatively, the size and pattern of openings **101** may be selected so that vacuum pressure is only applied to selected portions of the material web **1**.

The amount of vacuum pressure applied to the material web **1** may be determined by the density of the material web **1**, the feed rate of the material web **1**, the size of openings **101** in the cylindrical element **103** of the vacuum roller **3**, the strength of the vacuum source (such as a vacuum pump), the fluid properties of the liquid **5**, the properties of the liquid-pore or liquid-defect interface, and other factors. The amount of vacuum pressure may be controlled to

increase or decrease the differential pressure applied across the material web **1** so that defects **1b** of a particular size may be identified.

Each of the lateral ends of the vacuum roller may be sealed with an end cap **104**, which may act as a plug to seal the interior vacuum chamber **102**. The suction source of a vacuum pump or other pump may be attached to a vacuum pressure inlet **106** so as to create a trans-web pressure differential across the pores **1a** and defects **1b** of the material web **1**. In one embodiment, the one end of the vacuum pressure inlet **106** may connect to a vacuum pressure channel **110** that terminates at a channel opening **111**. The vacuum pressure channel **110** may have one or more channel openings **111** to transmit vacuum pressure to the interior vacuum chamber **102**. A inlet bearing **112** may separate the end cap **104** from the vacuum pressure inlet **106**. Alternatively, a rotary coupling may be used.

The effective contact area between the material web **1** and the cylindrical element **103** of the vacuum roller **3** may be determined in part by the location of the first and second rollers **2a** and **2b** (see FIG. 1), the diameter of the vacuum roller **3**, the size of the shield **107** and/or the percentage of openings **101** transmitting vacuum pressure at any instant, among other factors. The effective contact area between the material web **1** and the cylindrical element **103** of the vacuum roller **3** may be selected to ensure that the desired differential pressure is applied to the pores **1a** and defects **1b** of the material web **1** under steady-state conditions.

One or more of these factors may be changed in order to increase or decrease the effective contact area between the material web **1** and the cylindrical element **103** of the vacuum roller **3**. For example, in embodiments of the system, the cylindrical member **103** and vacuum pressure inlet **106** of the vacuum roller **3** may be supported by mounts **109a** and **109b**. The position of the cylindrical member **103** and the vacuum pressure inlet **106** of the vacuum roller **3** may be raised or lowered relative to the mounts **109a** and **109b** so that more or less of the material web **1** is submerged in the flushing chemical **5**. Alternatively, similar results may be accomplished by changing the configuration of the shield **7** so as to expose a greater or fewer number of openings **101** in the cylindrical member **103** of the vacuum roller **3**, thereby applying

vacuum pressure to a portion of the material web **1** for a longer or shorter period of time. In other embodiments of the invention, the effective contact area may be controlled by routing the material web around a series of roller assemblies, each of which may apply a different differential pressure across the material web **1**.

One or more of the first positional roller **2a**, the second positional roller **2b**, and the vacuum roller **3** may be driven and the remaining rollers may be undriven. By controlling the rotational velocity of the driven roller(s), the feed rate and tension of the material web may be controlled. In embodiments of the invention, both the first and second positional rollers **2a** and **2b** may be driven and their speeds may be independently controlled. In such a system, if the tension on the flushed material web exceeds desired amounts, the speed of the second positional roller **2b** may be reduced in relation to the speed of the first positional roller **2a**.

In embodiments of the invention in which the liquid **5** is drained away after it has been drawn into the vacuum roller **3**, the vacuum pressure inlet **106** may be positioned near the bottom of the cylindrical element **103** of the vacuum roller **3**. The vacuum pressure inlet **106** material is preferably chosen to be chemically compatible with the liquid **5**.

FIG. 4 shows a portion of an embodiment of the system in which the defects **1b** in the material web **1** are marked or repaired (depending on the post-processing device **302** used) after the defects **1b** have been identified. In embodiments of the present invention, the post-processing device may be a marker, such as an ink or dye dispenser, an etching device, or the like. When defects **1b** in the material web **1** are identified, an area on the surface of the membrane corresponding to the identified defect **1b** may be marked. For example, the area may be collocated with the defect **1b** or may be near an edge of the material web **1** at a point laterally displaced from the location of the actual defect.

Alternatively, the post-processing device **302** may be a repair tool, such as a adhesive dispenser, a welding instrument, a soldering iron, a laser or the like. In embodiments of the invention in which the post-processing device **302** is a adhesive dispenser, the identified defect **1b** may be repaired by covering the defect **1b** with a bead of glue, resin, epoxy or a similar

adhesive. The type of adhesive used may be chosen to suit the application for which the material web will later be used. The size of an adhesive bead deposited on the material web **1** may be chosen based upon the size and shape of the defect **1b**. In alternative embodiments, the post-processing device **302** may be a diffusion, heat, arc or other type of welding apparatus. In such an embodiment, the post-processing device may place a piece of material over the defect **1b** and weld the piece of material to the surface of the material web **1**. The size and shape of the piece of material may be based on the size and shape of the defect **1b** and, in particular embodiments of the invention, the piece of material may be cut from a larger material source based on the size and shape of the defect **1b**.

To accomplish accurate marking or repair of defects **1b** identified in the material web **1**, the differential pressures at which various defects **1b** in the material web **1** were identified may be recorded and associated with the identified defects. This information may be used to determine whether the defect **1b** is of a shape and size amenable to repair and what reparatory action is appropriate. Moreover, the locations of various defects **1b** may be calculated based on the images captured by the camera **6** and the speed and direction of travel of the material web **1**. A processor **301**, such as a computer or logic circuitry, may be used to calculate the location, size and/or shape of identified defects **1b**.

The location of the post-processing device **302** may depend in part upon the processing speed of the processor, the time necessary to transmit signals from the camera **6** to the processor **301** and from the processor **301** to the post-processing device **302**, and/or the speed and direction of travel of the material web **1**. Data indicative of the location of the defect **1b** to be transmitted by the processor **301** to the post-processing device **302** may include a two-axis coordinate pair corresponding to the location of the defect **1b** in the plane of the material web **1**, a time at which the defect will pass by the post-processing device **302** or some point related to the location of the post-processing device **302**, a speed and direction according to which the post-processing device **302** should be moved to intercept the defect **1b**, and the like.

While the embodiments particularly described above have generally focused on the use of a vacuum roller **3**, in other embodiments of the invention, vacuum pressure may be applied to the material web using a vacuum belt, vacuum table or similar device. In an embodiment using a vacuum belt or vacuum table, the material web **1** may be held against the vacuum belt or vacuum table by vacuum pressure applied through openings in the vacuum belt or vacuum table. The material web **1** may travel in the same direction as the portion of the vacuum belt or vacuum table against which the material web **1** is being held. Such an embodiment may also be used with a material web **1** that is not continuous, e.g. in the form of pre-cut sheets.

While the description above refers to particular embodiments of the present invention, it should be readily apparent to people of ordinary skill in the art that a number of modifications may be made without departing from the spirit thereof. The accompanying claims are intended to cover such modifications as would fall within the true spirit and scope of the invention. The presently disclosed embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than the foregoing description. All changes that come within the meaning of and range of equivalency of the claims are intended to be embraced therein.